Haptic Perception in Synaesthesia

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2 Abstract

Synaesthesia is a relatively rare phenomenon that, after several decades of neglect, has recently begun to be investigated in the scientific community. Despite advances in knowledge regarding both the underlying neurophysiology and phenomenology, it is virtually still in exploratory stages. The purpose of this project was to investigate haptic perception in synaesthesia from several different angles. First, we focused on several recent findings involving mirror-touch synaesthesia (Blakemore *et al.*, 2005; Banissy & Ward, 2007; Banissy *et al.*, in prep.) that promise a better understanding of intersubjectivity, both in terms of emotion recognition and spatial body mapping. Furthermore, we sought to establish a measure of authentication for touch-vision synaesthesia and to determine whether there may exist heuristics for cross-modal mapping, between synaesthetes and non-synaesthetes, that would have implications regarding the neural mechanisms of the phenomenon.

3 Introduction

a. *Synaesthesia: Defining Characteristics*

Synaesthesia is "a remarkable form of anomalous cross-modal, or intra-modal, perception" (Muggleton *et al.*, 2007: p. 1582). 'Synaesthesia' originates from the Greek *syn*, meaning "union," and *aisthises*, meaning "of the senses," literally expressing a "joining together" of two senses in one experience, so that stimulation of one sense modality automatically, involuntarily, and systematically elicits an anomalous conscious perception in either the same or an additionalsense modality. Synaesthetes, thus, may "see music," "taste shapes," and "feel colours" as they simultaneously hear music, taste flavours, and feel tactile sensations the way normal, i.e. non-synaesthetic, people do. The synaesthetic percept, thus, always exists in conjunction with, and never overrides, the "normal" percept, i.e. that of the inducing stimulus. Furthermore, most synaesthetes do not confuse their induced experiences with actual components of the external world (Rich & Mattingley, 2002). Synaesthesia is most likely unidirectional (Rich & Mattingley, 2002) and must always be elicited by a stimulus (MB); furthermore, the induced "two-dimensional" experience is automatic, highly consistent, and specific (Rouw & Scholte, 2007), in addition to often being quite vivid (Grossenbacher & Lovelace, 2001). However, there is much inter-individual variation, i.e. middle C may induce a shade of red for one synaesthete but a shade of green for another. Synaesthesia is regarded "as a special instance of the 'binding problem' in which two stimulus features (one veridical and one illusory) are combined into a unitary experience" (Banissy*et al.*, in prep.).

There are claims, though few have resulted from systematic investigations, that synaesthetes tend to be creative, artistic, and highly emotional individuals; that they are mostly left-handed; and that they suffer from left-right confusion, poor arithmetical reasoning, and/or deficient topographical cognition (Baron-Cohen *et al.*, 1996; Rich & Mattingley, 2002).

The eliciting stimulus is termed 'inducer' and the resulting experience the 'concurrent' – and the particular type of synaesthesia is always referred to in the corresponding inducer-concurrent pair, so that, for example, "touch-colour" denotes the form of synaesthesia in which tactile sensations induce coloured experiences (Grossenbacher & Lovelace, 2001). Although inducers can be representational, i.e. linguistic, concurrents normally comprise simple perceptual features like colour (Grossenbacher & Lovelace, 2001). Concurrents appear alongside non-synaesthetic perceptual experience, and they cannot be ignored, hence the use of modified Stroop tests in confirming the phenomenon (Mills *et al.*, 1999). Most, but not all, forms of synaesthesia span two sense modalities; for example, visual inducers may result in visual concurrents, as in grapheme-colour synaesthesia, arguably the most common. In this type of synaesthesia, ordinal sequences, i.e. the orthographic and/or phonological forms of digits, letters, and/or words, induce synaesthetic colour perceptions (Banissy*et al.*, in prep.; Rich & Mattingley, 2002; Simner *et al.*, 2006;). However, preliminary findings indicate that vision-touch synaesthesia could be just as common(Banissy*et al.*, in prep.).

There are two types of synaesthetes: those whose concurrent experiences are elicited perceptually, and those whose concurrent experiences are induced conceptually, i.e. merely by thinking about their corresponding inducers (Grossenbacher & Lovelace, 2001). Furthermore, there are two subtypes of synaesthetes: projectors, who experience their perceptions in a field of view external to their bodies, and associators, who report mental imagery in their "mind's eye."

b. *Prevalence*

In the adult population, the prevalence of synaesthesia has been estimated to be between 1 in 2,000 and 1 in 25,000, and even higher in infants/children, arguably being a feature of normal development that disappears with normal neural pruning following birth (Baron-Cohen *et al.*, 1996). Additionally, synaesthetes usually report more than one, and often

several, forms of the phenomenon; however, they normally manifest surprise upon learning that others do not share their same perceptual experiences and thus naively often fail to report their synaesthesia (Grossenbacher & Lovelace, 2001). Synaesthesia has been claimed to be about six times more common in females than in males, though recent evidence suggests that this may not be the case (Banissy *et al.*, in prep.). However, bearing this in mind, and also that it is common among biological relatives, synaesthesia has been hypothesized to result from a developmental, possibly genetic, predisposition, i.e. transmission by an X-linked autosomal dominant gene (Rich & Mattingley, 2002). Most cases are, in fact, congenital; however, there are also cases of developed synaesthesia following sensory deafferentation (Armel & Ramachandra, 1999), acquired blindness (Armel & Ramachandran, 1999; Steven & Blakemore, 2004), and ingestion of hallucinogenic substances, though the latter is currently subject of much debate (Grossenbacher & Lovelace, 2001).

C. *Neural Mechanisms*

There are several accounts regarding the neural mechanisms of synaesthesia, and they take place on two fundamental levels – a neurophysiological one and an architectural one. The former disputes whether there is anomalous structural connectivity in the brains of synaesthetes, either due to excess anatomical connections or to a failure in pruning following birth (Ramachandran & Hubbard, 2001; Mondloch & Maurer, 2004), or instead some form of disinhibition, mediated by entirely normal neural connections (Grossenbacher & Lovelace, 2001; Hubbard & Ramachandran, 2005). The latter centres on *how* cross-modal processing occurs, and whether it is due to (1) local cross-activation, (2) re-entrant processing, or (3) long-range disinhibted feedback (Hubbard & Ramachandran, 2005). The first refers to cross-activation between relevant, perhaps adjacent, perceptual areas, while latter two to abnormal feedback, either flowing back from a multisensory nexus (i.e., disinhibited feedback) or from

one relevant area to the other (i.e., reentrant processing) (; Hubbard & Ramachandran, 2005; Row & Scholte, 2007).

d. *Cross-modal Mapping*

If cross-modal mapping between inducers and concurrents is non-arbitrary, then it is likely that the neural and/or cognitive substrates underlying synaesthesia are not "privileged" but rather present in the normal, i.e. non-synaesthetic, population (Ward *et al.*, 2006), though they may not be consciously available. Thus, comparisons in cross-modal mapping between synaesthetic and non-synaesthetic populations are necessary in order to determine whether the two groups use similar heuristics for matching across domains. In fact, it has been found across both groups that higher pitches are matched to lighter colours and associated as smaller (Marks, 1974; Hubbard, 1996; Ward *et al.*, 2006); that grapheme frequency is directly related to colour luminance (Smilek *et al.*, 2007), with high frequency graphemes pairing with high frequency colour names (Simner *et al.*, 2005); that vibrotactile frequency, roughness, and pressureare matched to luminance, such that lower frequencies, rougher textures, and increased pressures map to darker colours (Martino & Marks, 2000; Ward, Banissy, & Jonas, 2008).

There are, in fact, cross-modal audiovisual areas present in the normal, i.e. nonsynaesthetic, brain (Calvert, 2001); these respond best when input originates from both vision and sound, rather than from just vision or just sound. These areas, for example, could form the neural basis for disinhibited feedback from cross-modal areas to unimodal areas in synaesthetes, thus causing perceptions in one sense modality to respond to stimulation from another sense modality. No extra pathways would be necessary, as, in this light, synaesthesia would result from hyperactive, but existing, connections.

e. *Touch in Synaesthesia*

Synaesthesia involving haptic perception is reported significantly less than other types of synaesthesia. Only 4.0% of synaesthetes report coloured touch (i.e. touch-vision), and 0.8% report tactile sensations on their own bodies when they watch someone else being touched (i.e. vision-touch) (Ward, Banissy, & Jonas, 2008). Vision-touch synaesthesia is not surprising in light of evidence showing that, in non-synaesthetes non-informative observation of body parts can affect haptic perception (Ward, Banissy, & Jonas, 2008). Thus, there is potentially much to be learned from investigations with vision-touch synaesthetes, as their conscious tactile perceptions allow direct access into *how* haptic perception is affected by changes in body posture, interpersonal representations of touch, and cross-modal processing. Similarly, investigations with touch-vision synaesthetes may allow for a deeper understanding of how tactile sensations are perceived, categorized, and interpreted above the level of nerve conduction.

4 Mirror-Touch Synaesthesia: Emotion Recognition

a. Introduction

i. *Shared Circuits*

If we are to deny solipsism and the idea that knowledge of anything outside our minds is unjustified, then the question arises of how we understand "other minds" and penetrate into the "inner worlds" of others. Though long established, these questions have recently resurfaced with great force in the scientific community, especially since the discovery of mirror neurons (Gallese & Goldman, 1998; Rizzolatti & Craighero, 2004) and their underlying principle: neural systems shared between first and third person perspectives, referred to as *shared circuits* (Keysers *et al.*, 2004; Keysers & Gazzola, 2006), that allow us to understand the actions,intentions, emotions, sensations, and even behaviours of others directly, effortlessly, and intuitively through a process of implicit *simulation* (Gallese & Goldman, 1998). Theories

involving shared circuits stand in stark contrast to more cognitive accounts of how we understand "other minds;" according to these, we employ deductive, more explicit mental processes referred to as *mentalizing*, and they are characterized by a conceptual, reflective, and declarative level of thought (Keysers *et al.*, 2004).

Interpersonal relations depend on our inherent human capacity to understand others. It is evident that, for the most part, we automatically, naturally, and effortlessly *share* in the sensations and emotions of others without necessarily engaging explicit thoughts, as through a *shared manifold of intersubjectivity* (Gallese, 2003), according to which we engage in automatic, unconscious simulation routines thus equating "self" with "other" in a shared manifold space. Current theories of embodied cognition suggest that understanding emotions involves perceptual, somatovisceral, and motoric re-experiencing of those same emotions in the "self" - termed *embodiment* – and evidence indicates that bodily expression of emotions influences the way in which emotional information is attended to and interpreted, bridging together "self" and "other" bodily expressions of emotion (Niedenthal, 2007). Theories of embodied cognition, encompassing concepts of re-enactment like simulation, resonance, and emulation (Niedenthal, 2007), are explainable in terms of a MNS that maps correspondences between performed and observed emotions.

The "classical" mirror neuron system (MNS) is activated by observation as well as execution of transitive, goal-directed actions, and thus it presumably provides the neural substrate for how we understand the actions of others, i.e. by "sharing" in them. This idea may also be applicable to emotions and sensations, for which the neural substrate could comprise an "extended" MNS representing *emotional* rather than simply *motor* componentsof bodily expressions (Carr *et al.*, 2003; van der Gaag *et al.*, 2007). Facial expressions can even be regarded as goal-directed if they are thought of as a "specific class of actions, not directed at a particular object, ...[but] as instrumental devices to influence other people" (Blair, 2003 as cited

in van der Gaag *et al.*, 2007: p.180). van der Gaag *et al.* (2007) propose an "extended" MNS for emotional states comprising the superior temporal sulculs (STS), insula, amygdala, pre-supplmentary motor area (pre-SMA), and somatosensory cortices (SI and SII). Rather than requiring visual and motor properties as the "classical" MNS does, this one would require visual and matching properties in other domains, i.e. emotions and sensations (Gallese *et al.*, 2004; Keysers & Gazzola, 2006), translating vision/ sound of what others feel into the observer's own feelings, thus linking first and third person experiences in a process of simulation (Carr *et al.*, 2003; Gallese *et al.*, 2004).

Brain regions previously implicated in shared circuits of emotion include the middle temporal gyrus (MTG), rostral inferior parietal lobule (PF/IPL), and ventral premotor cortex (F5/BA44+6) (Keysers & Gazzola, 2006), where the somatosensory cortices (and particularly SII as revealed by fMRI (Keysers *et al.*, 2004)) are involved both in experiencing touch on one's own body as well as in viewing touch to others, and the anterior insula is involved both in the experience of disgust and in the observation of disgust in others (Keysers & Gazzola, 2006; Jabbi *et al.*, 2007). Pfeifer *et al.* (2008) propose that the frontal component of the MNS (i.e., pars opercularis and adjacent ventral premotor cortex) could modulate activity within the limbic system (i.e. the amygdala) via connections through anterior insula.

Recognition of static emotional expressions depends on somatosensory related cortices in the right hemisphere (RH) (Adolphs, 2002; Anderson & Phelps, 2000). Damage to the right somatosensory cortex impairs subjects in the recognition of basic emotional expressions presented visually; and lesions to SI and SII, the anterior supramarginal gyrus, and the insular cortex result in difficulty in the comprehension of emotional expressions. These findings suggest that somatosensory cortices act as an affective convergence zone for understanding emotions (Anderson & Phelps, 2000), that observation of an emotional facial expression leads to a corresponding emotional response in the perceiver in the form of a representation in

somatosensory cortices that, in turn, endow the perceiver with information regarding that emotion (Adolphs, 2002). Recognition of emotional expressions, thus, depends on right somatosensory cortices and reflects mapping of the conveyed emotional expression directly onto one's own internal representation of the corresponding state (Anderson & Phelps, 2000).

Evidence from recent studies indeed indicates that shared circuits may exist for touch, and also for emotions. Keysers & Gazzola (2006) report that experiencing touch to one's own legs and seeing someone else's legs being touched activates SI and SII; and that, additionally, amount of activation correlates with empathic levels. Blakemore *et al.* (2005) report a neuro-imaging study of C, a mirror-touch synaesthete who shows significantly stronger activations than non-synaesthetic control subjects in somatosensory cortices when she observes someone else being touched, potentially explaining why observing touch to others results in her *literally* feeling equivalent tactile sensations on her own body, and also raising the question of whether stronger amounts of activation might correlate with higher empathic levels. Indeed, mirror-touch synaesthesia correlates with heightened empathic ability, specifically with the emotional reactivity subscale of the EQ (Banissy & Ward, 2007). Additionally, C shows significantly stronger activations than non-synaesthetic control subjects in left premotor cortex. Together, the patterns of activation indicate hyperactivity in the MNS for touch, above the threshold for tactile perception (Blakemore *et al.*, 2005). She also shows activations in anterior insula bilaterally, and no such activations were observed in non-synaesthetic control subjects. This area has previously been implicated in attribution to the self (Farrer & Frith, 2002 as cited in Blakemore *et al.*, 2005), potentially explaining why she perceives herself as the direct target of observed touch; and also in the internal representation of subjective feeling states (Craig, 2002; Craig, 2003; Critchley *et al.*, 2004). Because all three of these brain regions have been implicated in emotion perception (Adolphs, 2002), it is possible that mirror-touch synaesthetes

may be more sensitive to the recognition of emotions in visually presented faces, and be more empathetic.

ii. *Experiment*

Hyperactivity in somatosensory cortices of mirror-touch synaesthetes not only potentially explains synaesthetic tactile experiences, but also appears to be instrumental for recognizing emotions in visually presented faces. Thus, mirror-touch synaesthetes may perform better in an emotion recognition task involving the identification of facial expressions in visually presented faces. Furthermore, the associated activations may contribute to higher empathic levels. This experiment thus aims to investigate whether mirror-touch synaesthetes will perform better than non-synaesthetic control subjects in a forced-choice task involving recognition of emotions in visually presented faces.

b. Methods

i. *Participants*

Mirror-touch synaesthetes (7 females and 2 males) were recruited from self-referral or via prevalence, and had a mean age of 38.3 ± 15.7. Controls subjects (12 females and 8 males) were recruited from the University College London Psychology Subject Pool, and were age- and gender-matched to synaesthetes. Mirror-touch synaesthesia was confirmed for all mirror-touch synaesthetes prior to testing; they watched a video in which someone else was being touched on the hands and were instructed to respond whether they felt tactile sensations on their own hands and, if so, to indicate on which hands they felt the induced perceptions. All gave their informed written consent and were monetarily compensated. (See Table 1)

Name	Gender	Age	Sub-Type
LB	Female	59	Specular
DA	Female	18	Specular
JC	Female	63	Anatomical
MS	Male	42	Specular
HG	Female	38	Specular
FM	Male	29	Specular
KR	Female	19	Specular
PM	Female	44	Specular
FR	Female	35	Specular

Table 1. Summary of 9 mirror-touch synaesthetes who participated in Emotion Recognition Task.

ii. *Visually Presented Faces*

Faces were selected from the Karolinska Directed Emotional Faces set (Lundqvist *et al.*, 1998). There were both male and female faces, and each expressed one of the following four emotions: happy, sad, fear, and disgust. Each face was morphed between neutral and expressive states using Abrosoft FantaMorph 4.0 at five varying morph levels: 10% expressive, 90% neutral; 30% expressive, 70% neutral; 50% expressive, 50% neutral; 70% expressive, 30% neutral; and 90% expressive, 10% neutral.

iii. *Emotion Recognition Task*

The task involved forced-choice recognition of emotional expressions presented visually on a computer screen. A black and white face appeared on the computer screen for 500 ms seconds, after which a black screen appeared for a maximum of 6 s prompting participants to choose which of four emotions (happy, sad, fear, and disgust) they believed the face was expressing. The four letter keys corresponding to the four emotions were displayed ("s" for

happy, "d" for sad, "g" for fear, and "h" for disgust) so that participants did not have to memorize answer choices. All participants were instructed to respond as accurately, but as quickly, as possible. All participants were first given a practice block, consisting of 20 stimuli, and after given a chance to ask questions, they were instructed that there would be one block of 200 stimuli lasting between five-ten minutes.

c. Results

i. *Accuracy*

Analysis 1: Percent Accuracy on Overall Performance

A 2 (Group) x 4 (Emotion Type) repeated-measures ANOVA was conducted to determine whether there were significant effects between the two groups (synaesthetes *versus* controls) on accuracy scores across the four emotion types (happy, sad, disgust, fear). A significant main effect of emotion type was found, $F(3,81) = 42.14$, $p < .001$. Bonferroni corrected post-hocs revealed this difference was due to subjects performing significantly better on trials involving happy and sad facial expressions relative to disgusted and fearful facial expressions ($p < .001$ for all comparisons). No significant main effect of group or interaction was observed.

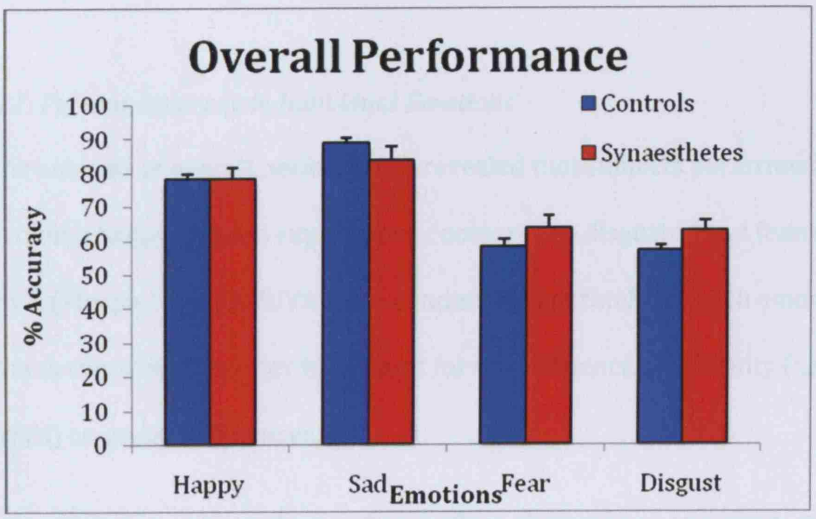


Figure 1. Overall Performance on Individual Emotions, as Measured in % Accuracy.

Additionally, a 2 (Group) x 5 (Morph Level) repeated-measures ANOVA was conducted to determine whether overall performance between groups differed across the five morph levels (10%, 30%, 50%, 70%, 90%). The main effect of morph level reached significance, $F(3.02, 108) = 514.07$, $p < .001$, with subjects showing higher accuracy rates with increases in morph levels for all morphs levels aside from the 70% and 90% morph levels ($p < .001$ for 10% and 30% morph levels, $p < .05$ for 50% and 70% morph levels). No main effect of group or interaction was observed.

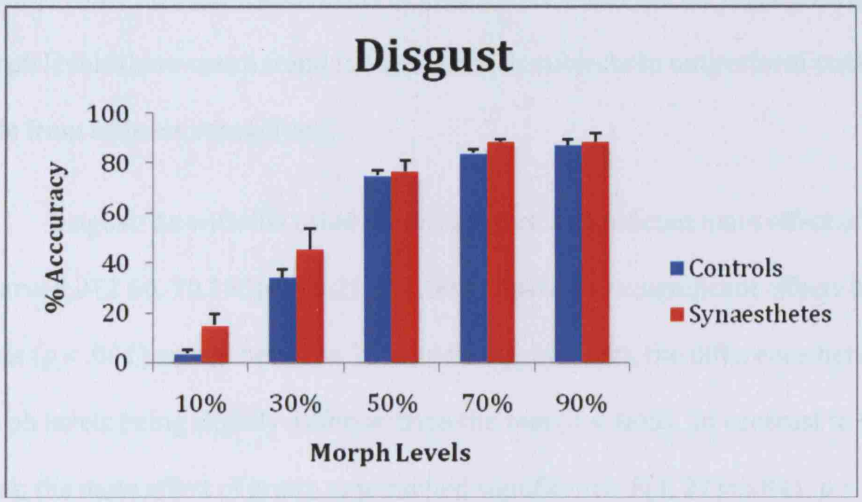


Figure 2. Overall Performance in Individual Morph Levels, Across Emotions, as Measured in % Accuracy.

Analysis 2: Percent Accuracy in Individual Emotions

As analysis of overall performance revealed that subjects performed better overall on trials involving happy and sad expressions compared to disgusted and fearful expressions 2 (group) x 5 (Morph Level) ANOVA were conducted separately for each emotion type. This analysis was conducted in order to account for any influence of difficulty (i,e, ceiling effects on easier trials) on group differences.

Happy, Sad, and Fear: No significant effect of group was observed. Significant within-subjects effects were however found for each emotion type: $F(1.707,46.086)=128.32$, $p < .001$

for Happy, F (2.108, 56.922) = 4.159, $p < .01$ for Sad, and F(2.733, 73.781)=149.563, P<.001 for Fear. Bonferroni corrected post-hocs revealed significant effects between certain morph levels, as following: for Happy, all morph levels (P<.001), except between 50%, 70%, and 90% morph levels, between which there were no significant effects; for Sad, only between 10% and 30% (P<.05), with all the others showing no significant difference; for Fear, all morph levels (P<.001 for all 10% and 30% morph levels, P<.01 for all 50%, 70%, and 90% morph levels), with the exception being between 70% and 90%, between which there were no significant effects. Notably, while no significant effects of group were observed for these trial types on lower morph levels there was a trend for synaesthetic subjects to outperform control participants aside from sadness recognition.

Disgust: As with the other emotion types, a significant main effect of morph level was observed, $F(2.60, 70.195)=299.25$, $p < .001$. There were significant effects between all morph levels ($p < .001$) except between 70% and 90%, and with the difference between 50% and 70% morph levels being slightly different than the rest ($p < .005$). In contrast to the other emotion types, the main effect of group approached significance, $F(1, 27)=3.841$, $p = .06$, with mirror-touch synaesthetes outperforming control subjects overall (i.e. across morph levels).(Figure 3)

Analysis 3: Sensitivity to Changes in Emotions

In order to determine if synaesthetes differed in their sensitivity to different emotions compared to control subjects, estimates of the percentage morph for which subjects reached 75% were calculated. This approach takes into account each subject's sensitivity to changes in emotion according to individual performance at each morph level using the following formula:

m75 = mlow + ((0.75 -mlow)/(phigh - plow)) (mhigh - mlow)

m = morph level; p = trials correct / n; n = number of trials

high=the probability of correct response on the lowest morph level onwhich the subject responded correctly better than 75% of the time.

low=the probability of correct response on the highest morph level onwhich the subject responded correctly less than 75% of the time.

g75 =the hypothetical morph level on which the subject would have scored 75% had it beenpresent.

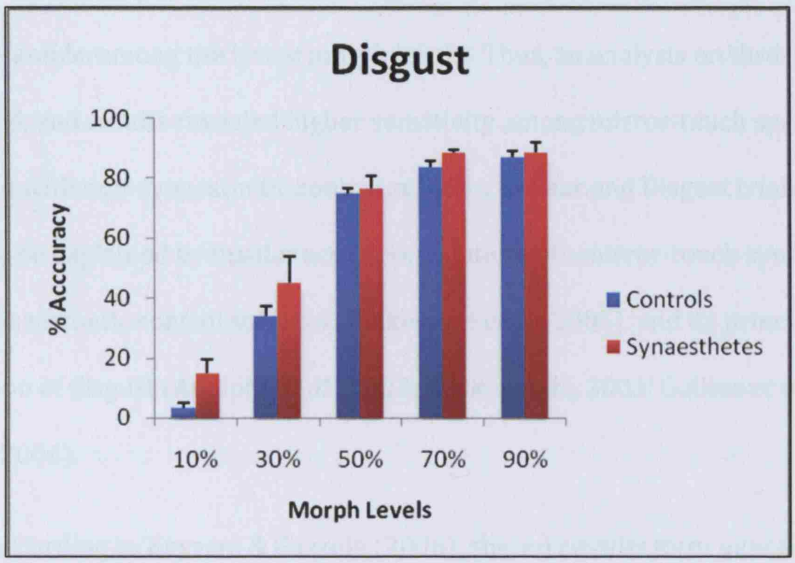


Figure 3. Overall Performance of Disgust, Across Morph Levels, as Measured in % Accuracy.

d. Discussion

Mirror-touch synaesthetes exhibitstronger patterns of activation in somatosensory cortices, anterior insula bilaterally, and premotor cortex, as compared to non-synaesthetic control subjects, when they observe touch to others (Blakemore *et al.*, 2005). These areascomprise a MNS for touch that is hyperactivated in mirror-touch synaesthetes, producing tactile sensations above the threshold for consciousness. Furthermore, these areas have been implicated in the recognition of emotions in visually presented faces. Thus, we hypothesized that mirror-touch synaesthetes would show greater sensitivity in, and thus perform better at, an emotion recognition task in which faces expressing four basic emotions (happiness, sadness, fear, and disgust) were presented visually on a computer screen. However, no significant effects

in overall performance were found between the two groups, neither per emotion and across morph levels norper morph level and across emotions. Although these results seem at odds with previous findings, they might be explainable in terms of the following: all participants performed exceptionally well on Happy and Sad trials, as well as on higher (i.e. 70% and 90%) morph levels, scoring close to or at ceiling, thus potentially masking differences in individual emotions and/oramong the lower morph levels. Thus, an analysis on thresholds was performed, and results revealed higher sensitivity among mirror-touch synaesthetes, as compared with non-synaesthetic control subjects, to Fear and Disgust trials. These results, in turn, may be explained by insular activation bilaterallyin mirror-touch synaesthetes, not found in non-synaesthetic control subjects (Blakemore *et al.*, 2005), and its principle role in the recognition of disgust (Adolphs *et al.*, 2003; Wicker *et al.*, 2003; Gallese *et al.*, 2004; Keysers & Gazzola, 2006).

According to Keysers & Gazzola (2006), shared circuits form neural correlates for both first person experiences and third person perspectives, and theycomprise the premotor cortex and the inferior parietal lobule interconnected with the MTG for actions, the somatosensory cortices for touch, the insula for disgust, and, despite contradicting evidence, the amygdala for fear. "Once shared circuits have transformed the... emotions of others into our own representations of... emotions, understanding other people's boils down to understanding ourselves..." (Keysers & Gazzola, 2006: p. 391). We do not confuse our experiences with our perceptions of others, because other brain areas clearly discriminate between these. For example, touch to one's own body elicits much stronger SI activation than observation of touch to others, with the exception existing in mirror-touch synaesthetes, who show reliable SI activity during observation of touch to others and may become literally confused about who is being touched (Blakemore et al., 2005). Thus, induced synaesthetic touch may have the same phenomenological feel as actual touch (Banissy & Ward, 2007).

The anterior insula is implicated both in the perception of disgusted facial expressions and in the experience of disgust (Keysers & Gazzola, 2006). In particular, the left anterior insula is selective for disgusting stimuli independently of their intensity (Gallese et al., 2004). fMRI confirms this finding (Wicker *et al.,* 2003), revealing overlapping activations in a sector within the anterior insuladuring the observation as well as the experience of unpleasant odorants; in fact, the only difference was the presence of *bilateral* activation during experience, as opposed to *unilateral* (i.e. left) activation during perception. These findings are further supported by previous studiesshowing activation of the anterior insula both during the observation and the imitation of facial expressions conveying basic emotions (Carr *et al.*, 2003). One brain imaging studyhas even shown that the amplitude of insular response depends on how disgusted the facial expression is (Phillips *et al.*, 1997). In line with these findings, patients with insular damage are unable to recognize disgust (Calder et al., 2000; Adolphs et al., 2003). In fact, this defect can extend into the auditory modality and become manifest in first person experiences, so that they experience a "blunted and reduced sensation of disgust" (Gallese & Goldman, 2004: p.5).

Penfield and Faulk (1955) observed that electrical stimulation to the anterior insula can produce sensations of nausea. Krolak-Salmon *et al.* (2003) reported that weaker stimulations to the anterior insula evokes unpleasant sensations in the throat and mouth. One implication of these findings is that observation of disgusted facial expressions induces, via activation of the insula, an internal representation of nausea in the observer (Gallese et al., 2004). Wicker *et al.* (2003) further reveal the insula's role in visceromotor integration, by showing that electrical stimulation to the human, as well as monkey, insula generates visceral sensations andcorresponding autonomic responses.In fact, the insula is evidently the main recipient of interoceptive afferents, denoting its importance in representing the interoceptive state of the body (Craig, 2002, as cited in Gallese *et al.*, 2004). Additionally, "it receives visual information

from the anterior sectors of the ventral bank of the superior temporal cortex, where cells have been found in the monkey to respond to the sight of faces (Wicker *et al.*, 2003: p.657).As a shared circuit, then, this system could account for the experience and for the understanding of [the emotional state of] disgust, for instance when presented visually in an emotion recognition task.

It should be noted that there are studies revealing little to no differences within the MNS between individual emotions presented in facial expressions. Although disgust cannot be specified to the insula (van der Gaag *et al.*, 2007), these studies do report premotor and insular regions as more involved in the observation and execution of *emotional*, versus more *neutral*, facial expressions, i.e. blowing up the cheeks, which instead preferentially activate somatosensory regions. Thus, they can still be reconciled with bilateral insular activation as resulting in greater sensitivity to emotion recognition tasks, as seems to be the case for mirror-touch synaesthetes.

5 Mirror-Touch Synaesthesia: Interpersonal Representations of Touch

a. Introduction

i. *Body Schema & Peripersonal Space*

Body schema has classically been defined as an ongoing, mainly unconscious integration of successive proprioceptive signals (Maravita & Iriki, 2004). Recent research in neuroscience, however, has brought to light two new dimensions: first, the importance of *somatosensory* and *visual* signals in the construction of body schema; and second, body schema as not simply perceptual, but also *action-oriented*, and as such able to influence how space coding for action is represented. Maravita & Iriki (2004) show, for example, how space coding for action changes in

accordance with constantly updated, multisensory information about the body, i.e. body posture.

The discovery of bimodal neurons in intraparietal cortex of the monkey brain coding for somatosensory, as well as visual, information (Maravita *et al.*, 2003) triggered further investigations into how visuo-tactile space is represented and, further, how it is modulated by changesin body posture. It has been shown that when the hands are moved across space (i.e., from an uncrossed to a crossed posture), peripersonal space remains anchored to the hand and moves with it (Colby, 1998; Maravita & Iriki, 2004). Peripersonal space is classically defined as physical area within immediate proximity of the body, but it can also be defined as space *attributed to* the body (Whitley, Kennett, Taylor-Clarke, & Haggard, 2004). For example, the effective use of a tool can induce a plastic modification of the body schema, such that the tool becomes incorporated into the neural representation of the hand wielding it. This holds when tools are held in crossed positions (See Figure 4). Thus, visual stimuli presented at its tip may be coded similarly to those presented at the hand (Maravita *et al.*, 2003; Maravita & Iriki, 2004).

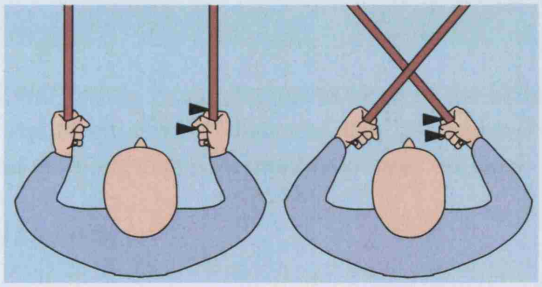


Figure 4(Maravita *et al.*, 2003)**.** Effective training with a tool can induce a plastic modification of the body schema, such that the tool becomes incorporated into the neural representation of the hand wielding it. This occurs when tools are in crossed as well as uncrossed postures. For example, visual stimuli presented on the *left* side of space near the tip of a tool held in the *right* hand may be represented similarly to visual stimuli presented at the *right* hand.

Previous research has demonstrated that stimuli seen as distant reflections in a mirror view of one's own hands can activate the same neural networks representing peripersonal space, because they are coded as having a true source near the body (Maravita *et al.*, 2002).

Thus, cross-modal interactions between vision and touch are not necessarily modulated by lower-level information derived froma purely retinotopic system, but rather from higher-level cues. These are capable of recoding input from retinal projections as having a proximal source and representing interactions with touch as if arising from near space (Maravita *et al.*, 2002). Similarly, previous studies have investigated visual-tactile interference and demonstrated that visual distracters on tactile judgments interfere more strongly when visual distracters close to the hand are observed indirectly as distant mirror reflections than when these are observed directly at equivalent optical distances (Maravita *et al.*, 2002). Though seen at physical distances falling in extrapersonal space, they can become recoded as falling in peripersonal space near the hand. Thus, they can function like proximal visual stimuli when generating cross-modal interactions (Maravita *et al.*, 2002; Maravita *et al.*, 2003).

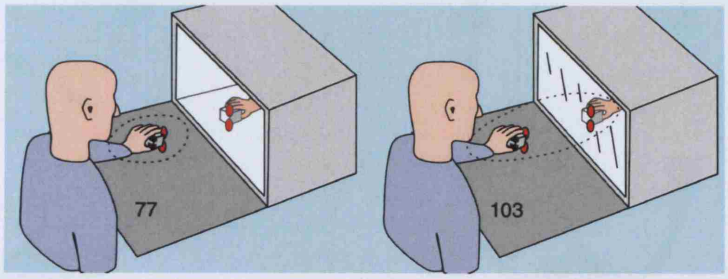


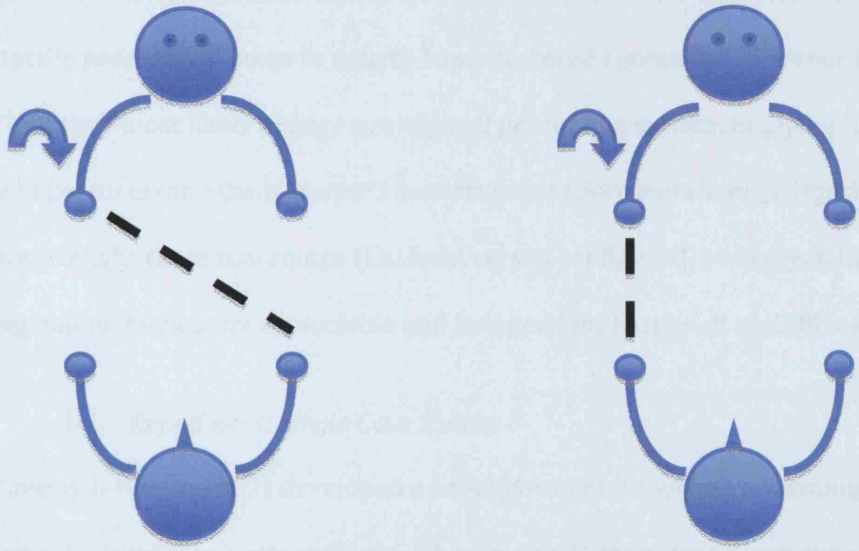
Figure 5(Maravita *et al.*, 2003).When visual distracters close to the hand are seen as distant mirror reflections, as opposed to at equivalent physical distances, they can become recoded as having a proximal source near the body and thus as falling in peripersonal space near the hand.

ii. *Spatial Mapping*

Evidence suggests that, in mirror-touch synaesthesia, observed touch is attributed to one's own body, such that mirror-touch synaesthetes become confused between induced and actual touch (Banissy & Ward, 2007). Thus, the effects of peripersonal space normally resulting from changes in one's own body posture may be conserved when mirror-touch synaesthetes observe changes in another person's body posture (Banissy *et al.*, in prep.). Just as tools can become incorporated into the body schema by enabling us to extend our reaching space, so may space "peripersonal to" observed touch that is attributed to one's own body. Thus, observed

touch may induce synaesthetic touch in the body part linked to that fragment of peripersonal space.

There are two subtypes of mirror-touch synaesthetes,*anatomical* and *specular*(Banissy & Ward, 2007). The former reports induced tactile sensations to the body part mapping anatomically to that of observed touch (i.e. left hand to left hand), while the latter reports induced tactile sensations to the body part mirroring that of observed touch (i.e. left hand to right hand, from a third person perspective).



a) *Anatomical* Synaesthete b) *Specular* Synaesthete

Figure 6. Arrows represent site of observed touch. a) *Anatomical* synaesthetes report induced touch to the body part mapping anatomically to that of observed touch (i.e. right hand to right hand). b) *Specular* synaesthetes report induced touch to the body part mirroring that of observed touch (i.e. right hand to left hand, from a third person perspective as shown above).

Presumably, the interpersonal frame of reference employed by the two subtypes differs (Banissy & Ward, 2007), and thus observed touch to another person's body partmost likely leads to different neural computations (Banissy *et al.*, in prep.). For specular synaesthetes, induced tactile perceptions seem extrinsically mapped to the *spatial location* of the observed

body part,rather than to a body-based representation (Banissy *et al.*, in prep.). Thus, they most likely engage a *local* processing system specialized in *local* details of body parts (Banissy *et al.*, in prep.), potentially the extrastriate body area (EBA) in the lateral occipito-temporal area (Downing *et al.*, 2001; Chan *et al.*, 2004; Urgesi *et al.*, 2007a). Recent research indicates that the right EBA may form part of a system used for processing *local features* of the human body, such as single body parts and body form, rather than *whole body configurations* (Downing *et al.*, 2001; Urgesi *et al.*, 2007a). Furthermore, it has been shown to respond more to allocentric views of people than to egocentric views, thus exhibiting sensitivity to the perspective from which bodies are viewed (Chan *et al.*, 2004; Urgesi *et al.*, 2007b). For anatomical synaesthetes, induced tactile perceptions seem to map to hand-centered egocentric reference frames (Colby, 1998). Thus, they most likely engage a *configural* processing system, implying "the embodiment of observed postures onto the observer's sensorimotor representations" (Urgesi *et al.*, 2007a: p. 8029). Accordingly, these two routes (i.e., local versus configural), both specialized for processing human bodies, are dissociable and independent (Urgesi *et al.*, 2007a).

iii. *Experiment: Single Case Studies*

Banissy & Ward (2007) developed a behavioural protocol for confirming the authenticity of mirror-touch synaesthesia. They showed that mirror-touch synaesthetes have difficulty in discriminating between actual and induced synaesthetic touch, because the two feel phenomenologically similar. In their study, participants were touched on the hands while they simultaneously observed an actor being touched on the hands in an uncrossed posture. However, they were instructed to ignore this. Instead, they were asked to report the site of actual touch. In the task, there were two conditions: congruent and incongruent. In congruent conditions, the site of actual touch was equivalent to the site of induced synaesthetic touch. In incongruent conditions, the site of actual touch was spatially different from the site of induced synaesthetic touch. Banissy & Ward (2007) showed that, in incongruent conditions, mirror-

touch synaesthetes were *slower* as well as more *error prone*, presumably because they became confused between actual and induced synaesthetic touch.

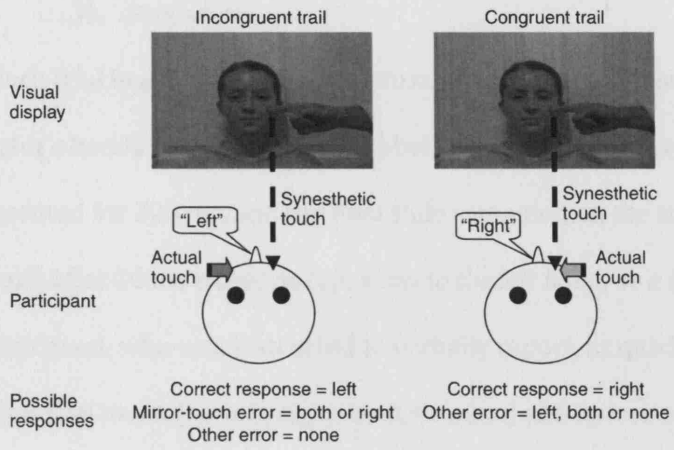


Figure 7 (Banissy & Ward, 2007) Schematic diagram showing incongruent *versus* congruent conditions, as employed in a new behavioural protocol designed to confirm the authenticity of mirror-touch synaesthesia.

The hands can be viewed from a first or third person point of view. For specular synaesthetes, a change in perspective requires an adjustment in spatial frames, if the induced tactile sensations are to be maintained as *mirroring* observed touch. This is not the case for anatomical synaesthetes. Here, we extend the findings of Banissy & Ward (2007) by manipulating the posture adopted by the actor to whom touch is observed (i.e. crossed *versus* uncrossed arms), thus investigating the influence of spatial coordinates on mirror-touch synaesthetic experience. Two single-case studies were conducted.

b. Methods

i. *Participants*

Both mirror-touch synaesthetes (2 females) were tested previously. One was recruited via self-referral and the other from the UCL undergraduate community. DP is a specular mirror-touch synaesthete, while JC is an anatomical mirror-touch synaesthete. Control subjects (9

females) were recruited from the University of Sussex. All participants gave their informed written consent.

ii. *Procedure*

Each trial began with a fixation cross, after which four consecutive slides showing a female actor's hands (either left or right) being touched were presented. The first three slides were presented for 200 ms, and the final slide remained on the screen for the duration of the trial, though after 10 ms either *no tap*, a *tap to the left hand*, or *a tap to the right hand* was given to the participant, who was instructed to verbally report, as quickly and accurately as possible, the site of actual touch (i.e. left, right, both, or none) and ignore observed touch, including any induced synaesthetic tactile sensations. No taps were given to both hands simultaneously. Participants completed 40 congruent, 40 incongruent, and 40 no-touch trials from first and third person perspectives. Trials were randomized within each block. Participants were instructed to keep their own hands out of view, palms-down, in an uncrossed posture. They wore ear protectors in order to prevent them from hearing taps.

Subjects were measured in two respects: *reaction time* and *number of errors*. Reaction times were noted for congruent and incongruent trials, from both perspectives. If induced synaesthetic touch feels like actual touch, then the incongruent condition may produce interferenceby the former in discrimination of the latter. In other words, it may confuse synaesthetes regarding "which touch" is actual and "which touch" is induced. The number of errors were counted and further classified according to *type*, i.e. whether they could be considered mirror-touch errors or not. A "mirror-touch error" is one in which the response given is consistent with induced synaesthetic touch, and it is indicates interference of induced synaesthetic touch on discrimination of actual touch. A non mirror-touch error, hereon referred to as "other error," is one in which the response given is *not* consistent with induced

synaesthetic touch, and it cannot be explained by interference of induced synaesthetic touch on discrimination of actual touch.

c. Results

Only reaction times(RTs) forcorrect trials were analyzed. Mean differences between incongruent relative to congruent trials (i.e. incongruent RT – congruent RT) were calculated for each perspective and then collapsed across both perspectives. These represent how much longer subjects take to discriminate actual touch on incongruent trials than on congruent trials.RTs were analyzed for all nine control subjects, but number of errors was analyzed only for eight control subjects, owing to missing data for one. We used a modified t-test (Crawford & Garthwaite, 2002) to detect significant differences between control subjects and each single-case study, i.e. DP and JC.

i. *DP (Specular) – Reaction Times*

DP was significantly slower than control subjects in discriminating actual touch in both congruent and incongruent conditions, and both from first as well as third person perspectives.

DP	Own Cong	Own Incong	Other Cong	Other Incong
***p* value**	$p < .01$	$p < .05$	$p < .05$	$p < .05$
***t* value**	t = 3.14	t = 2.40	t = 2.50	t = 1.95

Table 2. Summary for DP showing how significantly slower her RTs were relative to control subjects, in individual congruent and incongruent conditions, from her own and from the other's perspectives.

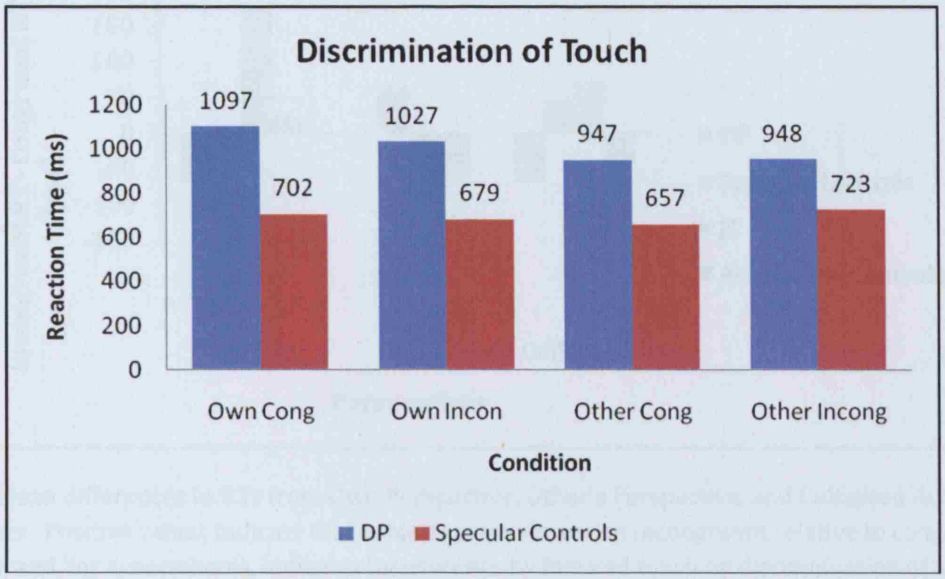


Figure 8. RTs for DP, as compared with control subjects, for congruent and incongruent conditions, from her own and from the other's perspectives. She was significantly slower than control subjects in all.

Mean difference between incongruent relative to congruent trials, from first as well as third person perspectives, did not differ significantly from control subjects. Collapsed across both perspectives, mean difference between incongruent relative to congruent trials differed significantly from control subjects ($p < .005$, t = -.352), though not in the expected direction, i.e. DP was significantly faster on incongruent relative to congruent trials, as compared with control subjects.

DP	Mean Dif, Own	Mean Dif, Other	Mean Dif, Collapsed
***p* value**	$p = .27$	$p = .09$	$p < .005$
***t* value**	t = -0.65	t = -1.43	t = -3.52

Table 3. Summary for DP showing how significantly mean differences in RTs (i.e. incongruent RTs – congruent RTs) differed, as compared with specular control subjects.

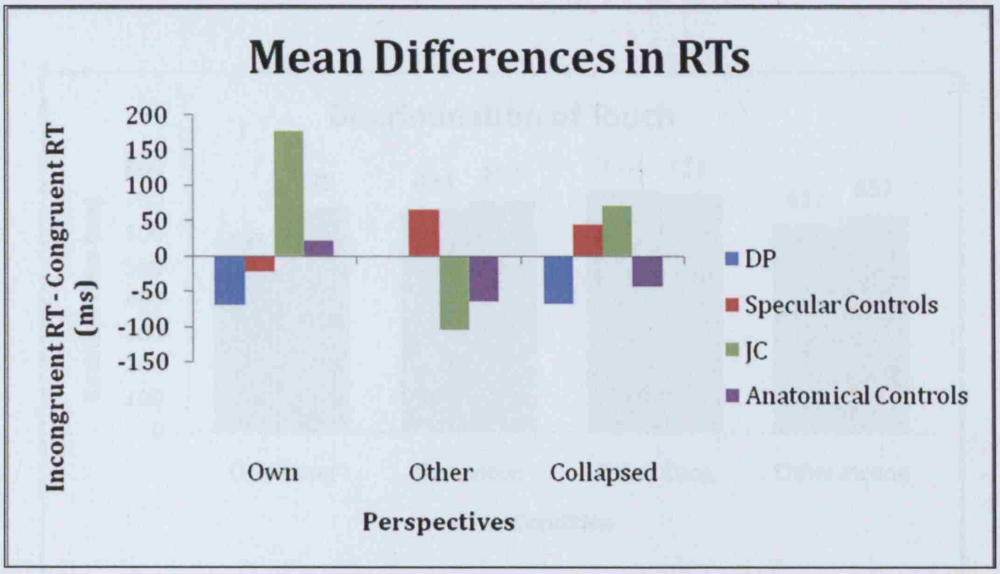


Figure 9. Mean differences in RTs from Own Perspective, Other's Perspective, and Collapsed Across Perspectives. Positive values indicate that subjects were slower on incongruent relative to congruent conditions; and, for synaesthetes, indicates interference by induced touch on discrimination of actual touch. **a) Own Perspective.** JC was significantly slower, as compared with anatomical control subjects, on Incongruent relative to Congruent trials. **b) Other's Perspective.** Neither DP nor JC were significantly slower, as compared with control subjects, on Incongruent trials relative to Congruent trials.

ii. *JC (Anatomical)– Reaction Times*

JC was not significantly slower than control subjects in discriminating actual touch, neither in congruent nor incongruent conditions, and neither from a first nor third person's perspective.

JC	Own Cong	Own Incong	Other Cong	Other Incong
***p* value**	$p = .119$	$p = .412$	$p = .468$	$p = .398$
***t* value**	t = -1.27	t = -0.23	t = 0.08	t = -0.27

Table 4. Summary for JC showing her RTs did not differ significantly from those of control subjects in individual congruent and incongruent conditions, from her own and from the other's perspectives.

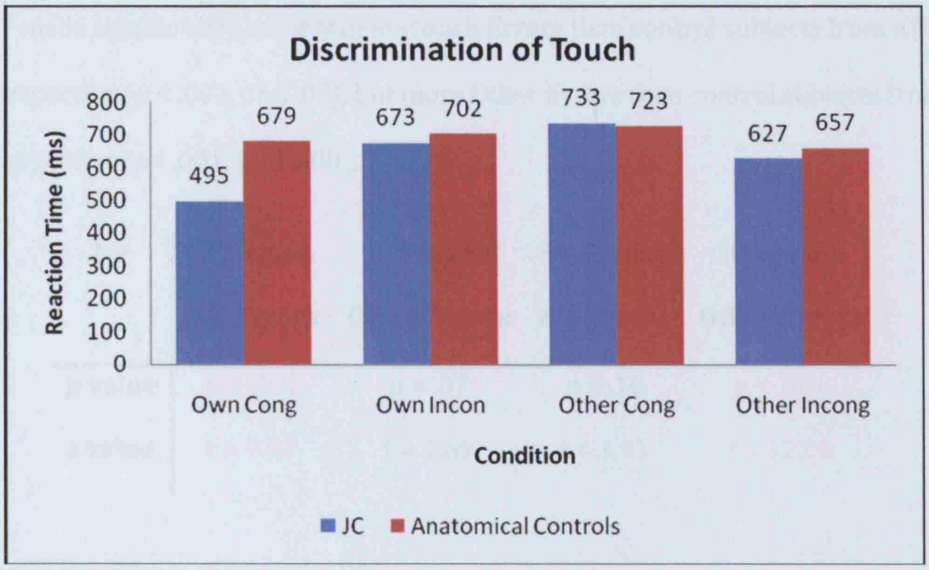


Table 5. RTs for JC, as compared with control subjects, for individual Congruent and Incongruent conditions, from her own and from the other's perspectives. She was not significantly slower than control subjects in any.

Mean difference between incongruent relative to congruent trials, from a first person perspective, was significantly larger than that of control subjects ($p < .05$, $t = 2.12$), indicating that she was significantly slower than control subjects in incongruent, relative to congruent, trials. This was not the case from a third person perspective, for which she did not show any significant differences from control subjects. Collapsed across both perspectives, however,mean difference between incongruent relative to congruent trials differed significantly from control subjects ($p< .005$, $t = 3.60$) in the expected direction, i.e. JC was significantly slower on incongruent relative to congruent trials, as compared with control subjects.

JC	Mean Dif, Own	Mean Dif, Other	Mean Dif, Collapsed
***p* value**	$p < .05$	$p = .20$	$p < .005$
***t* value**	$t = 2.12$	$t = -0.89$	$t = 3.60$

Table 6. Summary for DP showing her RTs did not differ significantly from those of control subjects in individual congruent and incongruent conditions, from her own and from the other's perspectives.

iii. *DP (Specular) –Mean Errors*

DP made significantly more Mirror-Touch Errors than control subjects from a first person perspective ($p < .001$, t = 7.07), but more Other Errors than control subjects from a third person perspective ($p < .001$, t = 12.00).

DP	1st Person MT Errors	1st Person Other Errors	3rd Person MT Errors	3rd Person Other Errors
***p* value**	$p < .001$	$p = .07$	$p = .10$	$p < .001$
***t* value**	t = 7.07	t = 1.69	t = 1.41	t = 12.00

Table 7. Summary of Types of Errors for DP.

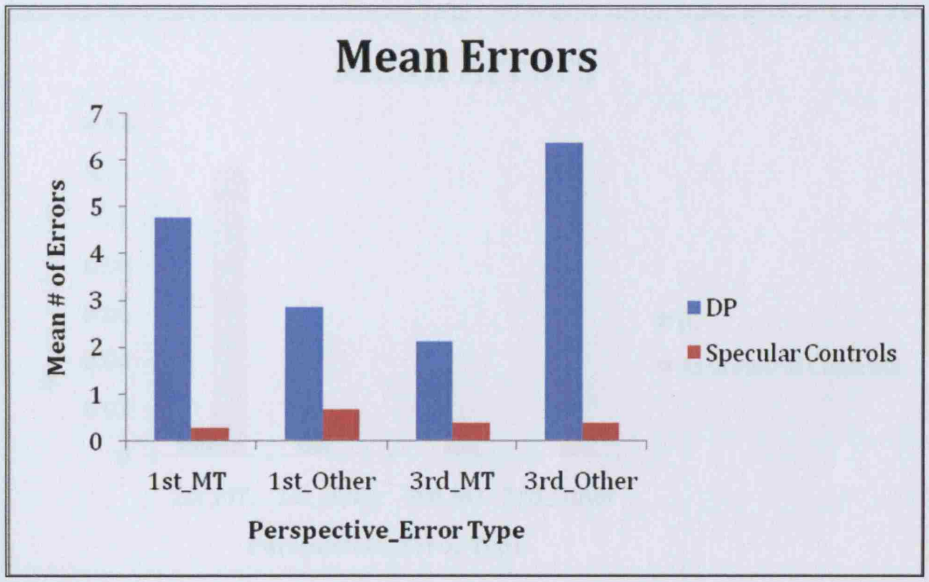


Figure 10. Summary of % Errors made by DP.

iv. *JC (Anatomical) –Mean Errors*

JC made did not make significantly more Mirror-Touch Errors than control subjects from either perspective, but she made significantly more Other Errors than control subjects from a first person perspective ($p < .05$, t = 2.41).

JC	1st Person MT Errors	1st Person Other Errors	3rd Person MT Errors	3rd Person Other Errors
***p* value**	$p = .38$	$p < .05$	$p = .20$	$p = .38$
***t* value**	t = -0.33	t = 2.41	t = -0.88	t = -0.31

Table 8. Summary of Types of Errors for JC.

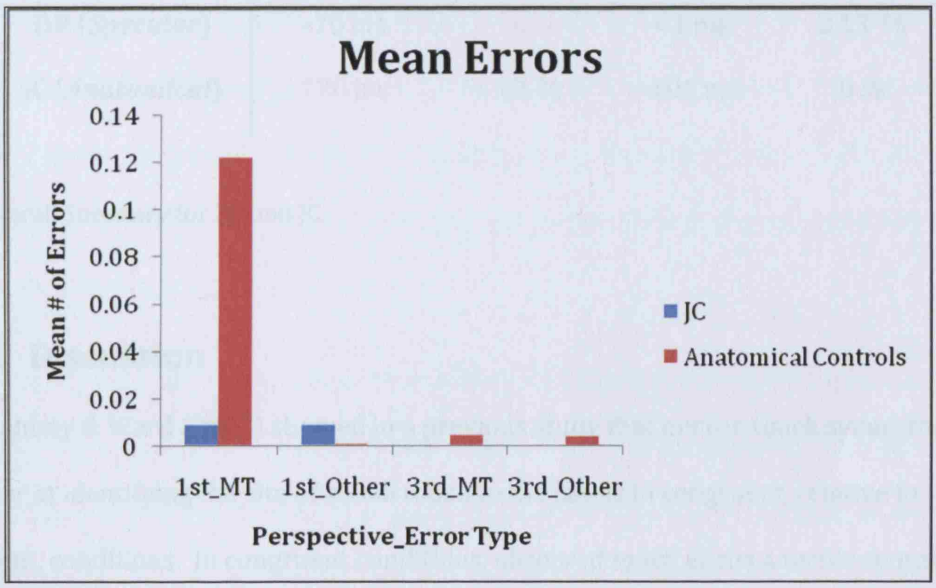


Figure 11. Summary of % Errors made by JC.

v. *Mean Differences in RT versus Mirror Touch Errors*

Mean differences in RTs for incongruent relative to congruent trials (i.e. incongruent RT – congruent RT) indicate how much slower participants were in discriminating actual touch on Incongruent trials than on Congruent trials; and, for mirror-touch synaesthetes, is reflective of

interference by induced touch on discriminating actual touch. Mirror-Touch Errors, on the other hand, indicate erroneous responses*consistent with* induced synaesthetic touch; and, for mirror-touch synaesthetes, suggests that they are confounding induced touch with actual touch. Since both measures are indicative of confusion resulting from induced synaesthetic touch, we checked, for both synaesthetes and in both perspectives, where significant effects as compared with control subjects lay exactly. For first person perspectives, comparison revealed the presence of significant effects in at least one of the two measures for each synaesthete. For third person perspectives, comparison revealed no significant effects in either measure for either synaesthete.

Perspectives	**1st Person**	**1st Person**	**3rd Person**	**3rd Person**
RTs *versus* Errors	**Mean Dif RT**	**MT Errors**	**Mean Dif RT**	**MT Errors**
DP (*Specular*)	-70 ms	4.76 %	< 1 ms	2.13 %
JC (*Anatomical*)	178 ms	< .01 %	-106 ms	0 %

Table 9. Overall Summary for DP and JC.

d. Discussion

Banissy & Ward (2007) showed in a previous study that mirror-touch synaesthetes were faster at identifying the site of actual touch to the hands in congruent, relative to incongruent, conditions. In congruent conditions, observed touch elicits a tactile sensation in the same spatial location as actual touch. In incongruent conditions, observed touch elicits a tactile sensation in a different spatial location as actual touch. Presumably, this occurs because induced synaesthetic touch has the same phenomenological feel as actual touch (Banissy & Ward, 2007).

Previous research shows that peripersonal space changes with body posture, so that when the arms move, for example from an uncrossed to a crossed posture, the space attributed to the hand moves with it. Thus, in a crossed posture, right space is attributed to the left hand, and vice-versa. Mirror-touch synaesthetes attribute observed touch to themselves. Thus, changes in body posture of an actor to whom touch is observed should have the same effects that changes in one's own body posture normally have. If the actor to whom touch is observed crosses her arms, right space should be attributed to the left hand. Specular synaesthetes, however, employ local processing where what is taken into account is spatial location of body parts, rather than engaging body-based, configural processing (the left hand has crossed to the left side of space).

DP was significantly slower than control subjects in determining which of her hands received actual touch in congruent and incongruent conditions, from both first and third person perspectives. However, in incongruent *relative to* congruent conditions, she did not perform significantly slower than control subjects. This indicates that induced synaesthetic touch may *not* have interfered with discrimination of actual touch, even though she was generally slower to react than control subjects.

In addition to this measure (i.e. mean difference in reaction times between incongruent and congruent conditions), a high proportion of mirror-touch errors may indicate interference by induced synaesthetic touch on discrimination of actual touch; and DP indeed showed significantly more mirror-touch errors than control subjects from her own perspective, indicating that induced synaesthetic touch may have interfered with discrimination of actual touch after all.

This was not the case from the other's perspective, for which DP instead made significantly more non mirror-touch errors than control subjects, suggesting either general task

difficulty, as these are presumably not caused by confusions derived from induced synaesthetic touch, or else possibly inconsistent locations for induced synaesthetic touch. Collapsed across both perspectives, however, DP was significantly slower than control subjects in incongruent conditions relative to congruent conditions, indicating that, in general, induced synaesthetic touch may have interfered with discrimination of actual touch.

JC, on the other hand, was not significantly slower than control subjects overall in determining which of her hands (left, right, both, none) received actual touch, rather than induced synaesthetic touch. She did perform significantly slower than control subjects in incongruent conditions relative to congruent conditions from her own perspective, though not from the other's perspective. She also, however, made significantly more non mirror-touch errors than control subjects from her own perspective. It is worth noting, however, that percentage of errors was still under 1%. There were no differences in performance between JC and control subjects in any regard from the other's perspective.

From the first person perspective, both mirror-touch synaesthetes can be said to have performed significantly worse than control subjects in a manner consistent with their induced synaesthetic touch. For DP it is apparent through the number of mirror-touch errors she committed, even though she did no worse than control subjects on incongruent versus congruent trials. For JC it is apparent through her significantly slower reaction times on incongruent versus congruent trials, despite the fact that she did no worse than control subjects in terms of mirror-touch errors. It seems evident that, at least for their own perspectives, the synaesthetes are exemplifying a speed-accuracy trade-off where the cost of speed on incongruent trials for DP is accuracy, or presumably confusion between synaesthetic versus actual touch; and the cost of accuracy for JC is speed, or slower reaction times in incongruent versus congruent trials.

From the third person perspective, neither synaesthete differed significantly from control subjects in any regard, with the exception being that DC committed significantly more non mirror-touch errors than control subjects. These findings are somewhat odd and may need to be explored through further testing. It is possible that a larger sample size is needed, as well as more mirror-touch synaesthetes. However, it is more probable that, as previously mentioned, mapping self to third person perspectives may be too difficult. In fact, evidence reveals that proprioception may reduce the impact of vision when visual information about hand position is inconsistent with body position (Maravita *et al.*, 2003). When hands are seen in an anatomically implausible posture inconsistent with one's actual posture, crossmodal influences on tactile judgements can disappear (Austin *et al.*, 2003 as cited in Maravita *et al.*, 2003). Visual information regarding body posture particularly influences body-part-centered multisensory spatial representations (Maravita *et al.*, 2003).

6 Touch-Vision Synaesthesia: Consistency

a. Introduction

Touch-vision synaesthesia is a relatively rare type of synaesthesia, having a prevalence of 3.8% within the synaesthetic population (Larner, 2006), and there are reports of developed (Armel & Ramachandran, 1999; Steven & Blakemore, 2004), in addition to congenital (Ward, Banissy, & Jonas, 2008), cases. It is characterized by the perception of coloured photisms projected onto externally located space or inside the mind's eye, elicited by tactile sensations.

Synaesthesia is a subjective phenomenon and thus, for a long time, it could only be identified through self-report. Consequently, it was neglected for several decades until a recent surge of interest inspired researchers to devise objective measures to confirm its presence in the individual. Because synaesthetes have proven to make fixed associations over time, consistency has been accepted as a significant indicator of the phenomenon. In tests of

consistency, inducer-concurrent pairings are analyzed for stability over time. To name just a few, grapheme-colour synaesthesia has been confirmed thus (Baron-Cohen *et al.*, 1987; Mattingley *et al.*, 2001), as have time-space synaesthesia (Smilek *et al.*, 2007) and sound-colour synaesthesia (Ward *et al.*, 2006).

Several studies report the development of touch-vision synaesthesia in late-blind individuals (Armel & Ramachandran, 1999; Steven & Blakemore, 2004). Armel & Ramachandran (1999) report the case of PH, who developed retinitis pigmentosa in early childhood and progressively lost his vision until, at age 40, he became completely blind. He experienced synaesthetic colour perceptions projected onto the spatial location of his stimulated body parts, irrespective of where they were in space. In fact, his synaesthetic colour perceptions were most easily induced when his stimulated body parts were 'in view' despite the fact that he was blind – for example, in front of, rather than behind, his head. Steven & Blakemore (2004) report six cases of late-blind individuals who retained synaesthetic colour perception after being deprived of vision for more than ten years, one patient of whom experienced coloured dots upon the touch (as well as thought) of Braille characters, with their geometric arrangement, rather than their meaning, mapping to particular colours.

Ward, Banissy, & Jonas (2008) describe two cases of congenital touch-vision synaesthesia: the case of RV, projector, and EB, an associator. Both were tested for consistency using 40 stimuli that varied along four dimensions: temperature, pressure, roughness-smoothness, and flutter, and that were applied to two different locations of the hand: palm and fingertip. Additionally, the colours that were matched to tactile stimuli were compared between synaesthetes and non-synaesthetes, since similar associations between the two groups implies universal cross-modal principles and has implications for the neural mechanisms underlying synaesthesia. Colour dimensions, i.e. chroma, luminance, and hue, were contrasted with aspects of touch, and results revealed significant correlations between roughness and luminance (where

rougher was darker) and between pressure and luminance (where higher pressure was darker). These were consistent across stimulation sites (i.e. palm or finger tip). Similarly, Martino & Marks (2000) have previously shown that vibrotactile frequency is matched to luminance, such that lower vibrotactile frequencies map to darker colours.

The aim of this experiment was to extend previous research in which consistency for touch-vision synaesthetes could not be confirmed (Ward, Banissy, & Jonas, 2008). Thus, (1) we tested two touch-vision synaesthetes, RC and MR, for consistency relative to non-synaesthetic control subjects, and (2) determined whether there exist significant relationships between types of touch (i.e. flutter, vibration, roughness, and grit values) and aspects of vision (i.e. colour dimensions, including hue, saturation, and luminance).

b. Methods & Materials

Participants

Control subjects (10 females and 9 males) were recruited through the University College London Subject Pool and were screened, by means of oral questioning, for touch-vision synaesthesia prior to testing sessions. All were right-handed, and age- as well as gender-matched to synaesthetes. All gave their written informed consent.

RC is a 33-year old, right-handed female. She reports experiencing touch-vision synaesthesia, though not consistently. In fact, she only claims to have experienced it vividly on a number of occasions. She is an associator synaesthete.

MR is a 34-year old, right-handed male. He reports experiencing touch-vision synaesthesia, though neither as strongly nor as consistently as his more dominant forms of synaesthesia, including tone-colour and grapheme-colour. He is an associator synaesthete. Furthermore, it is worth noting that he is currently being prescribed anti-depressants, which result in a general attenuation of his synaesthetic experiences.

Materials

There are four types of touch receptors, and each encodes different aspects of tactile perception (Vega-Bermudez & Johnson, 2001). On the glabrous surface of the hand, spacing between receptors, i.e. innervation density, varies both between digits and within digit surfaces (Sathian & Zangaladze, 1996). The sensory receptive fields with greatest sensitivity belong to the thumb and index finger of the dominant hand, hence their disproportionately large topographical representation in SI, particularly in Brodmann areas 3b and 1 (Overduin & Servos, 2004). Thus, the capacity for tactile discrimination varies among fingers; for example, spatial acuity thresholds correspond to innervation density (Vega-Bermudez & Johnson, 2001; Sathian & Zangaladze,1996), and precision manipulation (i.e. unbuttoning a shirt) reveals a progressive decline from the index to the ring finger. Thus, the chosen site of stimulation in this experiment was the index finger of the dominant, right hand.

A range of tactile stimuli were chosen, of four types:

Flutter. These are low frequency vibrations coded for by Meissner's corpuscles (Johnson, 2001). These were applied automatically by a bone conductor, in which a small probe exited at the following frequencies: 20 Hz, 40 Hz, 60 Hz, 80 Hz, and 100 Hz.

Vibration. Coded for by Pacinian corpuscles (Johnson, 2001), they were applied using neurological tuning forks of 128 Hz and 256 Hz.

Grit Value. These were applied manually.

Texture. Varying textures were applied manually, of the following qualities: hard, soft, smooth, rough, pointy, sticky, furry, even, and uneven. Several were organic items, and the rest were typical household items.

Colour Chart

Participants were presented with the computerised High Contrast Color Set (Laboratorio Immagini, ITIM-CNR, Milan, Italy).

Procedure

It is debated whether active and passive touch are perceptually equivalent (Chapman, 1994; Vega-Bermudez, 1991). Some studies claim that neuronal responses of the somatosensory cortex in response to touch are attenuated for self-produced, versus externally produced, tactile stimuli (Chapman, 1994). In primates, for example, cutaneous afferents to the spinal cord during active wrist movements result in presynaptic inhibition, possibly due to descending motor commands (Seki, 2003 as cited in Cullen, 2004). However, because attention and performance (i.e., motor commands at critical points) increase during active touch (Chapman, 1994), it is possible that active and passive touch actually are perceptually equivalent, all factors considered. Other studies reveal no discernable differences in performance, for example in tactile pattern recognition (Vega-Bermudez, 1991). Differences in scanning velocities (20 mm/s – 40 mm/s) produced no significant differences during passive touch, although a continual increase to 80 mm/s resulted in a progressive decline in accuracy. Although evidence is unclear, passive touch was the chosen method of stimulation; in part, to better control for inter-subject variations during active touch, so that stimulated touch receptors would vary as little as possible in order to avoid differences in tactile perceptions between subjects and across sessions.

Tactile stimuli were applied in a completely randomized order, and in a proximal-to-distal direction, i.e. from the base of the index finger to its tip. Subjects were asked to sit in quiet room with their right hand resting on a table, palm-up. A barrier was placed between subjects so that their right hands were completely out of view. They were instructed to choose the colour from

the Munsell colour wheel that they felt most accurately matched each tactile sensation. They were instructed to avoid making associations to objects, and instead attempt to focus solely on the sensation. At the time of testing, RGB (red, green, blue) values were noted down for each colour. All participants were told that they would be re-tested again on the same stimuli in a 2-3 week period.

c. Results

RGB Consistency

RGB distance values for inducer-concurrent pairings were compared for each touch-vision synaesthete relative to control subjects.RGB distance values were calculated using the following formula:

$$\text{SQRT}\ [(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2]$$

A modified t-test (Crawford & Garthwaite, 2002) was used to determine whether RC and MR were significantly more consistent than control subjects in their inducer-concurrent pairings across testing sessions. For RC, results were borderline significant ($p = .05$, $t = -1.83$). For MR, results were not significant.

H,S,L Consistency: Fingertip

A modified t-test (Crawford & Garthwaite, 2002) was used to determine whether RC was significantly more consistent than control subjects in individual colour dimensions, i.e. hue, saturation, and luminance, across testing sessions. RGB values were converted to HSL values using the following formula (http://en.wikipedia.org/wiki/HSL_color_space):

Let max be the greatest of *r*, *g*, and *b*, and min the least.

To find hue, compute:

$$h = \begin{cases} 0 & \text{if } \max = \min \\ (60° \times \frac{g-b}{\max - \min} + 0°) \bmod 360°, & \text{if } \max = r \\ 60° \times \frac{b-r}{\max - \min} + 120°, & \text{if } \max = g \\ 60° \times \frac{r-g}{\max - \min} + 240°, & \text{if } \max = b \end{cases}$$

To find saturation and luminance, compute:

$$s = \begin{cases} 0 & \text{if } \max = \min \\ \frac{\max - \min}{\max + \min} = \frac{\max - \min}{2l}, & \text{if } l \leq \frac{1}{2} \\ \frac{\max - \min}{2 - (\max + \min)} = \frac{\max - \min}{2 - 2l}, & \text{if } l > \frac{1}{2} \end{cases}$$

$$l = \tfrac{1}{2}(\max + \min)$$

For RC, results were borderline significant only for hue (p = 0.05, t = -1.79). For MR, none were significant.

Correlations

Cross-modal correspondences between four types of touch, i.e. flutter, vibration, roughness, and grit value, and aspects of vision, i.e. colour dimensions including hue, saturation, and luminance, were measured.

Significant correlations were found for the following:

-Flutter and Saturation, $p < .01$, r = -.294

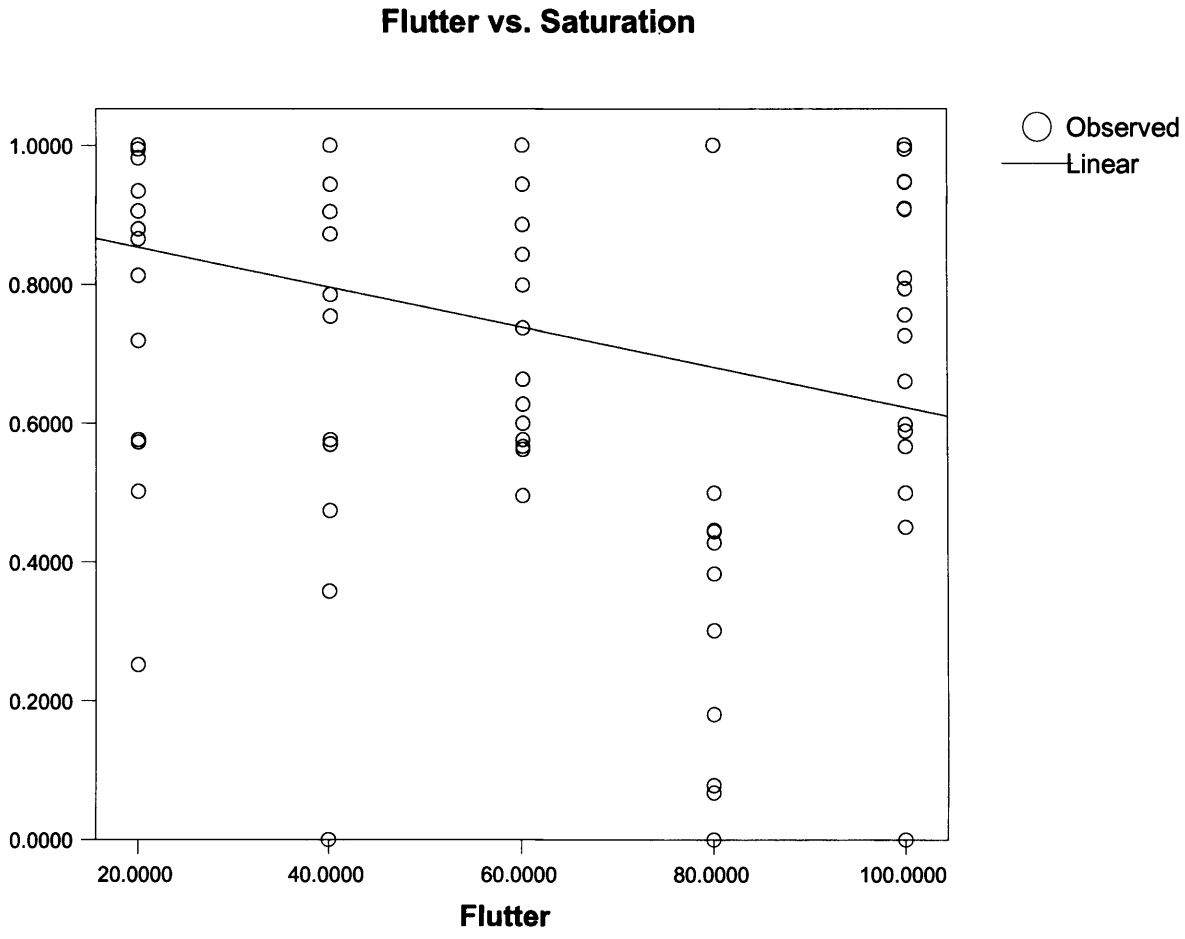


Figure 12.

-Roughness and Saturation, $p<.001$, r = -.572

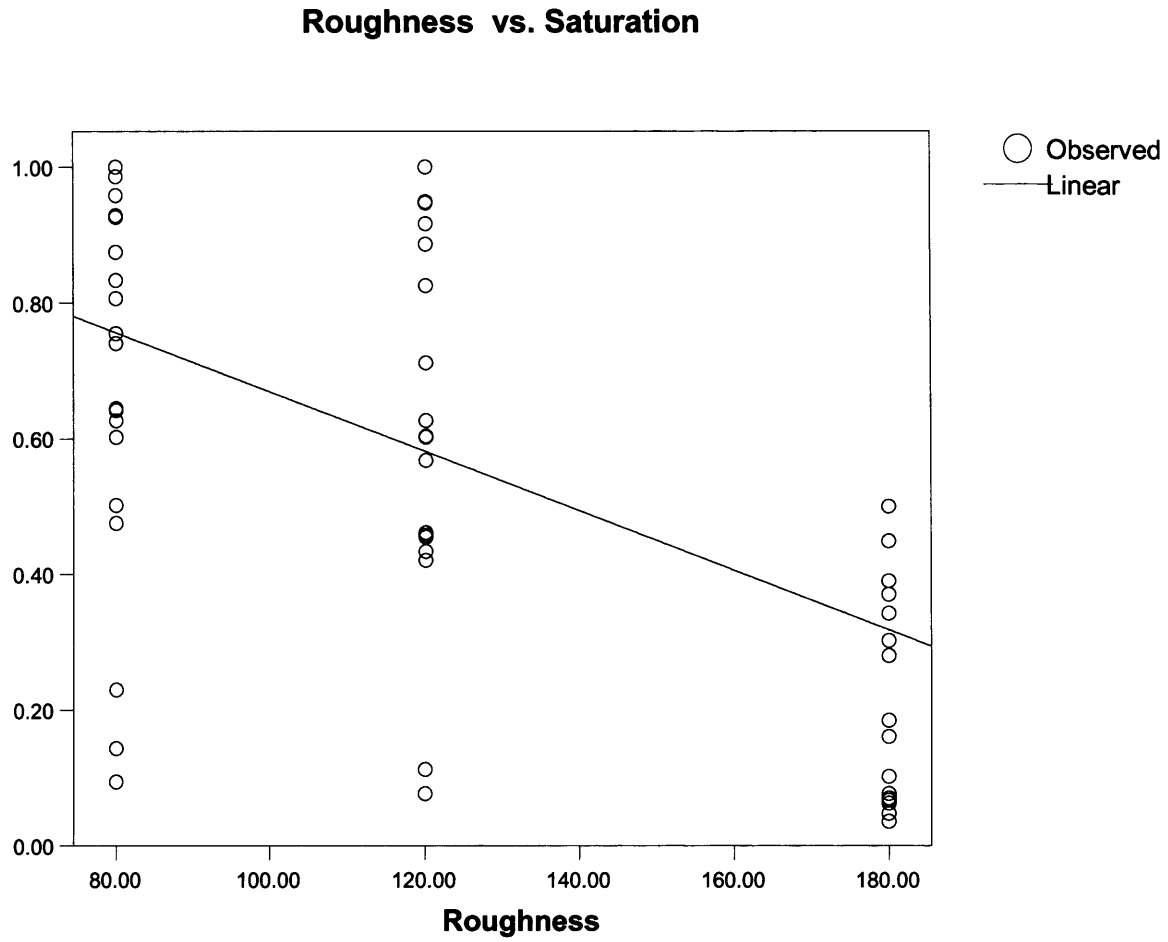


Figure 13.

-Grit Value and Saturation, $p < .001$, $r = -.403$

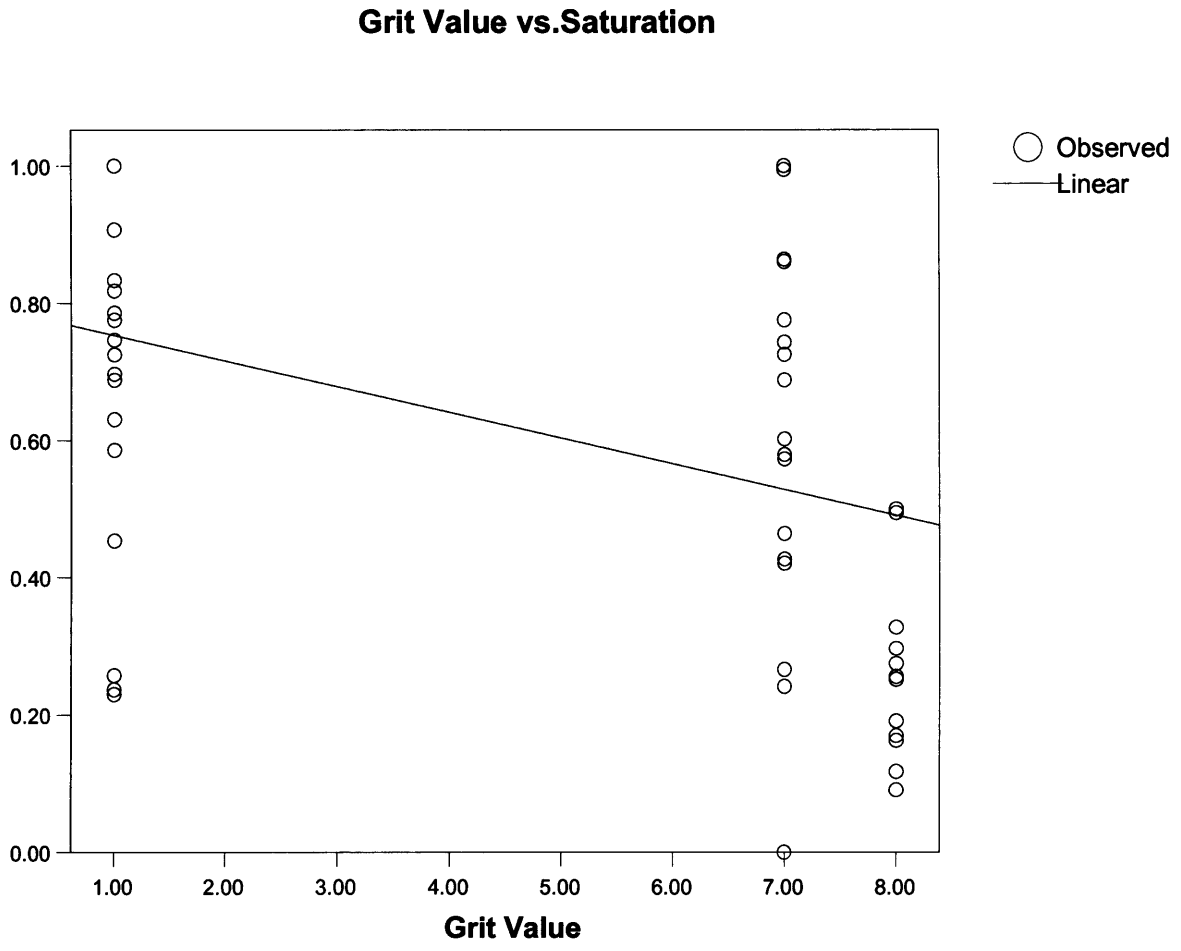


Figure 14.

-Grit Value and Luminance, $p < .05$, r = -.258

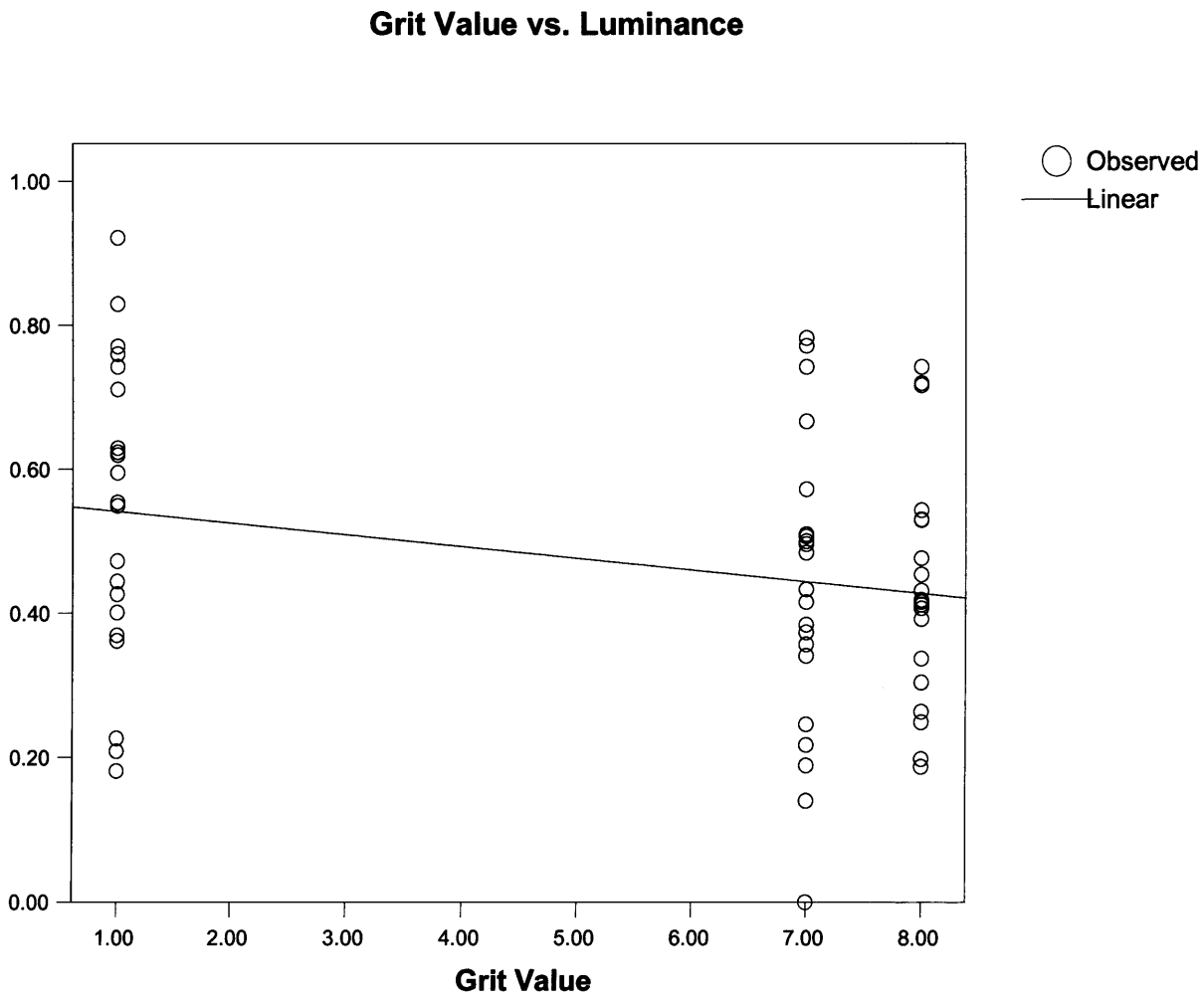


Figure 15.

d. Discussion

RC was borderline significantly more consistent, as compared with control subjects, in matching colours, as described in RGB distance values, to tactile stimuli; and, more specifically, in matching the colour dimension of hue to tactile stimuli. Although MR was not significantly more consistent, as compared with control subjects, in matching colours to tactile stimuli, it is worth noting that he made special mention that he was being prescribed anti-depressants, which he expressed significantly attenuate his synaesthetic experiences.

Correlations between types of touch and aspects of vision are relevant for the investigation into the neural bases of synaesthesia. That is, correlations in the same direction between synaesthetes and non-synaesthetes indicates similar associations and thus potentially similar neural connections across the two groups, as opposed to the presence of abnormal connections present in synaesthetes as compared with non-synaesthetes. Correlations were found between the colour dimension of saturation and flutter, roughness, as well as grit value; and, additionally, between luminance and grit value. All correlations were negative, so that as values increased, colour dimensions decreased. Although no correlations were found between vibration and a colour dimension, this may be due to the difficulty in applying tuning forks consistently between participants and across sessions. Flutter was applied automatically via a bone conductor, and both gratings and sandpaper were easier to control in terms of application to the skin than was vibration.

Although participants were instructed to divorce *what* they believed the stimulus was from *how* they perceived it, i.e. the *object* from the *sensation*, it is worth noting that during testing sessions many made verbal associations in three main ways, all or any of which could have biased them towards picking the similar colours in both testing sessions, and thus shown more consistency: (1) between the object they believed was being applied and the colour that that object normally is (i.e., brush bristles are generally brown); (2) between the object they

believed was being applied and the colour of an equivalent personal object (i.e., "This feels like my purple scarf, so I'll pick purple."); and (3) between the sensation of the object being applied and its presumed function (i.e. a needle prick was consistently associated with blood, and thus the colour red).

A fundamental problem with regards to the tactile modality compared to, for example, the auditory modality, is difficulty in controlling the stimulating variables. Touch receptors are undeniably sensitive to slight differences in application, with different nerves firing in response to, for example, a patting movement versus a sliding movement, as well as variations in pressure of the applied object and also temperature of both object and surroundings (Johnson, 2001). Tactile perception in glabrous skin is mediated by a variety of mechanoreceptors, each of which serve distinctly different perceptual functions. Form and texture perception, i.e. the spatial structures of objects, is mediated by Merkel cells. Static skin deformations, i.e. flutter, are coded for by Meissner Corpuscles, and higher frequency skin deformations, i.e. vibrations, are coded for by Pacinian Corpuscles. Direction of the motion of objects moving across the skin surface are coded for by Ruffini Corpuscles. Furthermore, application of most tactile stimuli was human and thus prone slight changes from one testing session to the next. These variations present problems for the isolation of one nerve, or one combination of nerves, and thus consistent tactile perceptions from one testing session to the next. In contrast, other types of synaesthesia may be better measured by consistency because of less variation in nerve types. For example, pitch is invariably the same and activates the same nerves, i.e. middle C always activates hair cells tuned to that frequency and that lead to the same perception across time; and more conceptual forms of synaesthesia, like grapheme-colour, are also more likely to invariably lead to the same perception, i.e. the letter B even in different handwritings is probably always perceived as a B and not as another letter. In contrast, the tactile modality is more multi-dimensional, with even one texture leading to different perceptions depending on

the mode of application and thus the nerve or combination of nerves stimulated, as well as factors from the surrounding environment like temperature and pressure with which it is applied to the skin.

6 General Conclusion

The purpose of this project was to investigate haptic perception in synaesthesia from several different angles. In part, this project sought to extend recent findings involving mirror-touch synaesthesia (Blakemore *et al.*, 2005; Banissy & Ward, 2007; Banissy *et al.*, in prep.), in which intersubjectivity was explored, as well as ongoing research in touch-vision synaesthesia (Ward, Banissy, & Jonas, 2008).

The first experiment involving emotion recognition and was based on previous findings indicating that that mirror-touch synaesthetes, show hyperactivity in the same mirror-touch networks activated in non-synaesthetes when they observe someone else being touched (Blakemore *et al.*, 2005). These brain regions are also implicated in the recognition of emotions in visually presented faces, and, furthermore, mirror-touch synaesthetes show higher empathic levels than control subjects (Banissy & Ward, 2007). Thus, we hypothesized that mirror-touch synaesthetes might be more sensitive in a task involving emotion recognition, owing to stronger activations in shared circuits mapping onto the emotional states of others, in what is referred to as the shared manifold of intersubjectivity. Results revealed lower thresholds than control subjects in the recognition of fear and disgust. In part, this may owe to activations bilaterally in insular cortex, which are not normally found in control subjects (Blakemore *et al.*, 2005).

The second experiment investigated the role of spatial mapping on mirror-touch synaesthesia by modulating body posture of an actor to whom touch was observed. Mirror-touch synaesthetes attribute observed touch to another's body to their own body, mapping self

to other using one of two spatial reference frames. Thus, we hypothesized that effects normally resulting from changes in one's own body posture would be maintained while observing changes to another's body posture. Results revealed that, while this may be the case from a first person perspective, it is not the case from a third person perspective.

The last experiment sought to establish a measure of authentication for touch-vision synaesthesia and to determine whether there may exist heuristics for cross-modal mapping, implying that synaesthesia is governed by neural mechanisms found in the normal, non-synaesthetic, population. Although consistency could only be established for one case study, RC, this may be a result of the extreme complexity of the tactile sensory system, on a very elementary level, in comparison with other modalities.

Haptic perception in synaesthesia is a promising field, as it has important implications for both the mechanisms underlying synaesthesia, as well as for how intersubjectivity and cross-modal mapping may operate in the non-synaesthetic population.

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